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## DESIGN CONCEPT OF UNSKIMED REINFORCED FORMS FOR INTEGRATED IMPROVEMENT OF CIVIC BUILDING PERFORMANCE

**Abstract.** The objective of this article is to analyze and propose ways of improving unskimed reinforced formwork being a forming unit of civic building performance. The authors propose integrated design concepts to wall unskimed reinforced forms ensuring integrated improvement of framework performance.

**Keywords:** performance, unskimed reinforced forms, civic building, integrated approach.

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## КОНСТРУКТИВНЫЕ РЕШЕНИЯ НЕСЪЕМНОЙ ЖЕЛЕЗОБЕТОННОЙ ОПАЛУБКИ ДЛЯ КОМПЛЕКСНОГО ПОВЫШЕНИЯ ЭКСПЛУАТАЦИОННЫХ КАЧЕСТВ ГРАЖДАНСКИХ ЗДАНИЙ

**Аннотация.** В данной работе объектом анализа и совершенствования являются конструктивные решения несъемной железобетонной стеновой опалубки как элемента, формирующего систему эксплуатационных качеств (ЭК) каркаса гражданского здания. Предложен комплекс конструктивных решений несъемной железобетонной стеновой опалубки, обеспечивающих комплексное повышение ЭК каркаса.

**Ключевые слова:** эксплуатационные качества, несъемная железобетонная опалубка, гражданское здание, комплексный подход.

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### Introduction

Ensuring significant increase of civic buildings performance necessitates the use of new methodological approaches that would enable realizing transitional changes at all stages of a building's lifecycle. Integrated approach is one of the design concepts, as it is the methodological basis of system engineering, which has been widely employed in recent successful business projects in construction, machinery manufacture, and other industries [1, 2, 3], as well as many modern megaprojects [4, 5].

The article [6] presents the Authors' approach to the integrated approach realization by means of improving a number of key performance parameters in order to increase civic buildings performance. The Authors study some buildings with cast-in-situ and precast frames given as an example. This Paper continues the research carried out in the article mentioned and provides an example of practical realization of the Authors' approach developed.

### Main part

The framework possesses the maximum effect in increasing the performance of modern civic buildings

currently implemented, especially in cast-in-situ and precast structures. Though, up-to-date formworks are widely used in the erection of cast-in-situ frameworks, the performance of some bearing structures under development is hardly to be satisfactory. Since formwork, reinforcement and concreting are all performed on the construction site, there appears performance degradation resulting from a number of defects caused by: off-design concrete range and arrangement of reinforcement, failure to maintain certain concrete cover thickness, overstandard plan and height deflections in the structure, smooth surface finish and overstandard deformations.

Being the rational trend in the development of construction processes, combination of cast-in-situ and precast reinforced concrete (RC) structures enables both reducing framework unsoundness and increasing the speed of erection, i. e. increasing its performance in an integrated manner. The application of unskimed reinforced forms is believed to be one of the concepts proving this trend is successfully implemented. Evidence from European technological and engineering manuals has proven that such kind of forms is popular among their engineers [7, 8]. Recent studies of civil engineer-

ing experience in Russia and the Sverdlovsk region in particular demonstrate the wide application of wall and bridging unskimed reinforced forms used with the reinforcing cage “Filigran” (hereinafter referred to as unskimed forms) produced under the German technology [9]. The national standards based on German construction codes were developed in 2011 and 2012 (STO NOSTROY 2.6.15–2011 and 2.7.16–2011). They provide construction specifications of the unskimed forms given, and generalize production and acceptance of cast-in-situ wall and bridging erection works as well. As we show later, the design concepts provided in construction codes, nevertheless, fail to ensure the increase of key parameters of the framework performance.



Fig. 1. Air pockets on the border of cast-in-place and precast parts of the core

Construction experience with unskimed formworks showed that their field of application is restricted significantly by climatic conditions at the construction site. Thus, the unskimed formworks are applicable only in the summer months for the Urals and Siberia (a wide area of the Russian Federation). The given restriction results mainly from hard-to-remove icing on the rough sheathing caused by cold-weather storing and assembling of a formwork (particularly during snowfall) and heating difficulties with thin prefabricated slabs. The above defines the field of the effective application of wall and bearing unskimed forms in a framework (retaining its performance): low-rise social housing and dwellings as high as 12 stories, i. e. skeletons erected within 4–5 months. One can conclude that wall unskimed formwork demonstrates maximum effect in improving structural framework performance.

The available design concepts of wall unskimed forms are not capable of providing the increase of key parameters of framework performance for the following reasons.

Space reinforcing cage and close panel distance (usually 100–120 mm) are hindrances to concrete mix com-

paction in unskimed forms. Having conducted testing of specimens (in the form of a core) drilled from precast in-situ wall, we concluded that using conventional internal vibrator fails to provide quality concrete mix compaction which, in its turn, results in air pockets on the border of cast-in-situ part with precast panels, thus reducing load-carrying ability of precast and cast-in-situ wall (Fig. 1). In addition, the volume gain of air pockets in the cast-in-situ part is caused by small area of the exposed mix surface between precast panels.

While pouring concrete mix in unskimed forms in the winter months, the problem is ensuring favourable temperature conditions for proper concrete curing, since it determines significantly the carrying capacity of cast-in-situ wall. That temperature is to be above zero in a cast-in-situ wall making task integrity necessary. In national construction codes (STO NOSTROY 2.7.16–2011) the provision is made for undershelters with heat-moisture covering being the principle concreting method with unskimed reinforced forms in use. The given engineering solution is hardly to be technological, moreover, it needs the application of heat generators and special covering materials.

Current construction codes on cast-in-situ structures installed in unskimed forms (STO NOSTROY 2.7.16–2011) make provision for ultrasonic method of nondestructive testing, which measures the ultrasonic speed coming through a precast panel before concreting and through a cast-in-situ structure afterwards. Constructional laboratory has to conduct ultrasonic testing of precast panels in operation before concreting, which is difficult to complete in the case of erection from “wheel” due to the obligatory laboratory assistant presence on the site. Furthermore, ultrasonic testing requires accurate measurement of precast panel thickness in the forms and the core. The emphasized requirements to ultrasonic testing reduce accordingly test reliability and practicability.

To avoid the flaws mentioned, the integrity of design concepts of wall unskimed forms was developed and patented in Russian useful models [9–11]. The wall unskimed reinforced formwork with the reinforcing cage “Filigran” was assumed to be a basis there. The given formwork is made up of two thin-walled RC flat reinforcing cages joined by space reinforcing cage, its upper and lower chords being placed in precast concrete. External surface is made smooth, while the internal one (sheathing) is rough.

Three design concepts of wall unskimed forms were developed to improve the key parameters of the performance.

The first concept (Fig. 2a) is implemented in every slab of the tiers of through ducts. The latter are located oblique to slab’s external and internal surfaces. Duct output on external slab surface is placed higher than that on the internal surface. Ducting in slabs allows ensuring high invariable carrying capacity of cast-in-situ core in

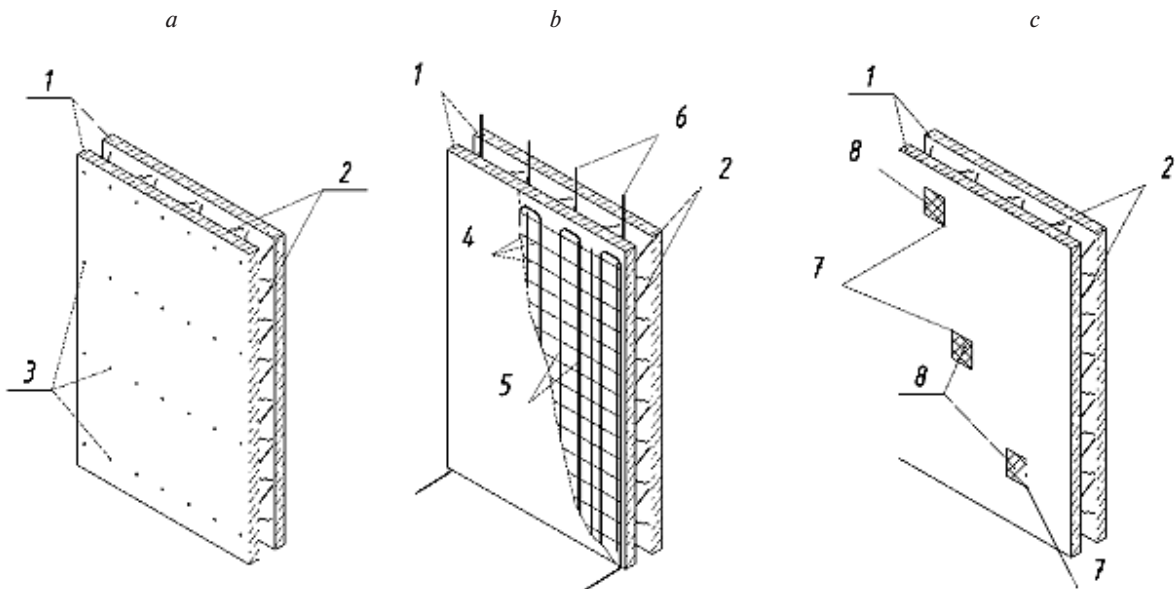


Fig. 2. Design concepts of wall unskimmed reinforced forms: a) – first, b) – second, c) – third:  
1 – thin-walled RC slab, 2 – space reinforcing cage, 3 – through ducts, 4 – flat reinforcing cage of the slab,  
5 – heating wire, 6 – rod electrode, 7 – through orifice, 8 – plug from porous materia

precast and cast-in-situ walls due to the exposed surface area growth in concrete mix and the provision of extra air outlet in the cast-in-situ part during its compaction. The suggested duct orientation guarantees air leaving, yet it does not permit concrete mix to flow out the forms.

The second concept (Fig. 2b) consists of placing (1) the heating wire in the flat slab reinforcing cage at the production stage; the heating wire has the form of heating spiral with ends exposed in the slab; (2) vertical rod electrodes in space reinforcing cage between slabs. Introduction of heating wires and electrodes ensures high invariable carrying capacity of cast-in-situ core in

test concrete strength in cast-in-situ core by means of conventional nondestructive tests, e.g. shock pulse method. There is no need of secondary geometry measurement of precast and cast-in-situ parts in order to test concrete strength in the formwork structure. The concept makes it possible to employ technologically effective nondestructive concrete strength testing and obtain error-free strength assessment of cast-in-situ core. This said, operative, organizational and technological solutions can be made to enhance reliability probability of precast and cast-in-situ wall. The range of improved key parameters of wall framework perfor-

Ensuring key parameters to increase the performance of precast and cast-in-situ walls by design concepts of wall unskimmed forms

Design concepts of unskimmed forms	The range of improved key parameters of wall frame performance						
	1	2	3	4	5	6	7
The first concept [9]	+	+	+	+	+	+	+
The second concept [10]	+	+	+	+	+	+	+
The third concept [11]	+	-	+	-	+	+	+

*Comment.* The following key performance parameters of wall framework are figured in the table: 1 – reliability probability of structures; 2 – structural deformations; 3 – turnaround time; 4 – durability of concrete; 5 – arrangement of reinforcement; 6 – concrete cover; 7 – plan and height position of structures in standard regulations.

precast and cast-in-situ walls at the cold-weather concreting stage.

The third concept (Fig. 2c) is in the through orifices filled with porous plug and made in one of the formwork slabs at the production stage. The number of orifices, their area, and the location of orifice boundary are defined according to nondestructive testing regulations. The presence of air pockets in slab formwork filled with easily removable material results in accessibility to cast-in-situ core surfaces so that to

mance (marked by pluses in the table) was defined for each design concept.

Implementation of the developed design concepts of wall formwork is believed to ensure high design reliability of concrete pouring and consolidation and raise processibility and reliability of concrete strength testing in the cast-in-situ part, i.e. to improve key performance parameters of framework walls in civic buildings.

## Conclusion

The following conclusions are drawn from the results of the research conducted:

1) Application of unskimed reinforced forms is one of the integrated approach implementations to improve civic buildings framework performance. Meanwhile, wall unskimed reinforced formwork has the maximum effect in fulfilling this task.

2) For further improvement of precast and cast-in-situ wall performance, design concepts of unskimed forms are recommended to be used in order to ensure:

- high technological reliability of concrete mix pouring and consolidation in cast-in-situ core [9];
- temperature conditions available for fast strength development in winter concreting [10];
- high reliability and processibility of concrete strength tests in cast-in-situ core [11].

The developed design concepts of wall unskimed forms have been efficiently employed both in Russia and Nordic countries (Sweden, Finland and Norway).

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